FRONTAL EVOLUTION IN LAYERED MODELS: MIXED LAYER DYNAMICS AND THE STABILITY OF FORCED FRONTS

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LONG-TERM GOAL

The long term goals of this project are to gain new understanding of oceanographic frontal processes and the role that fronts in the open ocean play in the exahcnage of fluid parcels form the surface ocean to the thermocline.

SCIENTIFIC OBJECTIVES

The scientific objective of this project are several fold, first to determine the underlying dynamics of unstable fronts and the circulation associated with the evolution of frontal structures, both in adiabatic and in non-adiabatic models. The second objective is to create a mixed-layer model embedded in an isopycnal model for future oceanographic applications.

APPROACH

Using a two-dimensional model, the circulation associated with an evolving front in the presence of strong vertical mixing has been studied. An adiabatic isopycnal model has also been used to study the equilibration of unstable fronts and the associated adiabatic vertical criculations and movement of fluid parcels. A slab-mixed-layer model has also been used to study the evolution of an unstable front in the presence of vigorous mixing and forcing. We have coupled the mixed-layer model to the adiabatic mixed-layer model and have tested a new approach which is described below.

WORK COMPLETED

A paper has been written and submitted on the two-dimensional modeling (Thompson, 1997), and two-papers have been written and submitted on the study of the equilibration and associated circulations of an adiabatic front (Boss and Thompson, 1997a and 1997b). Boss defended his Ph.D. dissertation in December of 1996 and will be starting a post-doc at Oregon State University

The coupling of the mixed-layer model to the isopycnal model has been done. Testing of the one-dimensional version has been completed, and continuing testing of the three-dimensional version has been done. A new scheme has been developed with Robert Hallberg of GFDL for the coupling of the mixed-layer to the isopycnal layers. This scheme involves the introduction of a buffer layer which allows both heat to be conserved as well as mixed-layer depth. Satisfying both of thses conditions has been problematic in previous efforts.

We used the slab mixed-layer model to study the evolution of fronts in the presence of both forcing and virgorous vertical mixing.

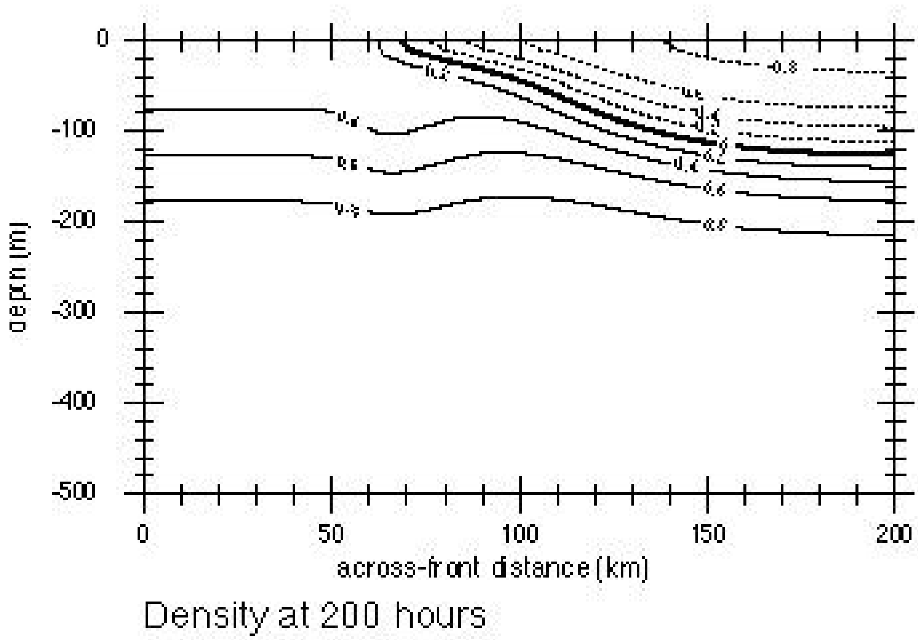

Figure 1. Density section after 200 hours in the two-dimensional numerical model. The initial condition was representative of the FASINEX front. There is no external forcing applied, but there is an elevated vertical mixing coeffiecient.

RESULTS

The two-dimensional modeling described above showed that vertical mixing associated with Ekman layers driven by the presence of geostrophic shear can cause significant modifications to a density section. In particular, downward bowing of isopycnals appears beneath the surface expression of the front (Figure 1) . This is very reminiscent of features seen in FASINEX (for instance see Pollard and Regier, 1992). The dynamical explaination of this features contribute to our understanding of how fluid parcels move in the viscinity of a front (Figure 1).

With the study of the equilibration and non-linear evolution of a baroclinically unstable front, the accuracy of both the quasi-geostrophic approximation has been tested, and the usefulness of quasi-linear theory in describing the finite amplitude evolution of the unstable system. This was done by analyzing the zonal mean meridional transport across a two-layer zonal jet in both quasi-geostrophic and finite Rossby number models (Figure 2). It was found the the quasi-linear theory does a remarkably good job inpredicting the zonally averaged cross-front structure, even at finite amplitude. In addition, quasi-geostrophic theory also appears to work reasonably well, as long as the correct scaling for the deformation radius is used. The seeds of the equilibration of the instability also appear in the quasi-linear analysis and can be used to understand the dynamical evolution of the unstable jet even at large time.

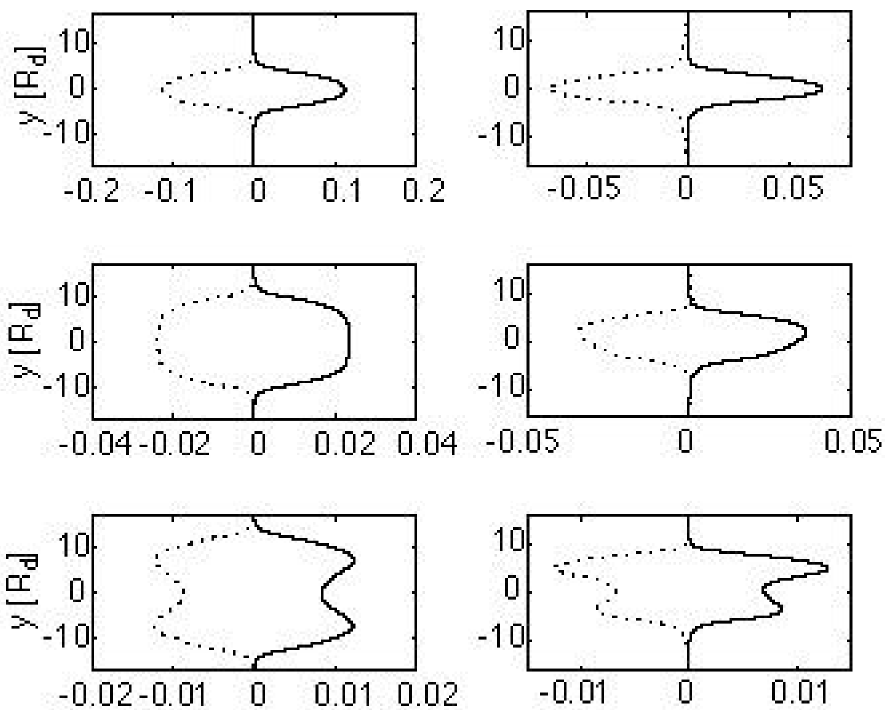

Figure 2. The zonal mean of the meridional mass transport in both layers of a two-layer baroclinically unstable flow. They transport is shown for three different times, and for the quasi-geostorphic approximation (left panels) and for a finite Rossby number flow (right panels). Notice the similar ities both between the quasi-geostrophic and non-quasi-geostrophic flows and between the mass transport early in the evolution and that later in the evolution. The finite Rossby number results show an asymmetry forming which is not seen under the quasi-geostrophic approximation.

Using the same initial flow configuration, the isopycnal model was also used to study the movement of tracers and floats in an unstable jet. Using generalized Lagrangian Mean theory, the Stokes drift byt he unstable waves was found to be of primary importance. The meridional drift is the direct result of the instability and there are convergence of centroids of particles to the stirrings lines of the flow where the jet and phase speeds are equal (Figure 3).. The zonal mean tracer evolution was also formulation and the relationship of the eddy-diffusivity to the movement of fluid parcels was discussed. Mixing (as opposed to stirring) is observed to be maximum due to formation of cat's-eye-likerecirculation regions in between the meanders in the upper layer. Inthe lower layer the pattern of convergence and divergence of theflow increases tracer gradients locally, however, with a much slower mixing rate than in the upper layer. Comparison with previous studies reveals that baroclinic instabilityhas a distinct role in tracer mixing -- particularly in finite amplitude.

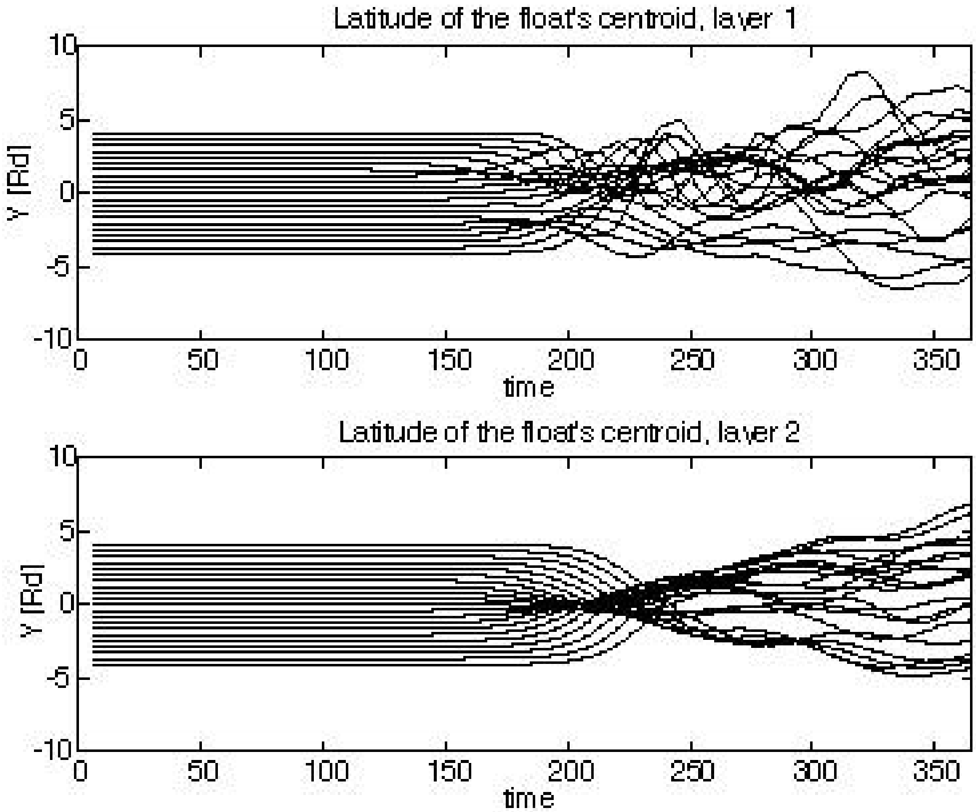

Figure 3. The zonally averaged lattitude of a line of floats in the shallow water model as a function of time. Notice the lines of convergence in each layer. There are two in the upper layer and they are predicted by the quasi-linear theory, and there is on in the lower layer. After time of about 200, the meanders grow to finite amplitude and the quais-linear theory no longer apply as the lines of floats fold back on itself.

Work continues on the development of a new formulation of a bulk mixed-layer imbedded in the isopycnal model (with Robert Hallberg). We have formulation that allows the conservation of heat and reproduces a reasonable seasonal cycle (in a one-dimensional sense). The three-dimnesional version is running and will be tested in a model of the North Pacific soon.

The stability of a forced front has also been studied. In that case, a mixed-layer front is produced and shows that north-south asymmetries can quickly appear when wind-forced convergence is at work.

IMPACT/APPLICATION

The impact of the work with the isopycnal model is significant as it reorients how the dynamics and mixing characteristics of jets such as the Gulf Stream can be interpreted. The coupling of the mix-layer model to the isopycnal model will have important significance in modeling on all scales, from process studies the impact of atmospheric forcing on loca physical oceanographic phenomenon to climate modeling.

RELATED PROJECTS

The work outlined is related to two other projects, one with ONR support, and the other with NASA support.

1. The quasi-linear analysis described above for the isopycnal model has been applied to the problem of coastal trapped waves under support from ONR.

2. With NASA support, the isopycnal model and the mixed-layer model is being used to explore the generation of annual period free and forced Rossby waves in the North Pacific. The application of the model to the North Pacific has been successful and initial results show the impact of variable forcing and topography on the wind-forced motions.

REFERENCES

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ABSTRACT

The study of evolving unstable fronts in the ocean was the focus of this work. Several approaches have been taken. The cross-front structure in a mean sense was studied in several different ways, first with a quasi-two-dimensional model where the influence of Ekman layers on the evolving front was explored. Second, an adiabatic isopycnal model was used to explore the equilibration of a baroclinically unstable front and the net exchange of mass and fluid parcels across the mean jet both at both small and finite amplitude. In addition, the quasi-geostorphic approximation was tested in this context and found to be a good predictor of flow at finite amplitude, baring an asymmetry in cross-frontal structure that appears when the Rossby number gets big. Mixed-layer models in the context of baroclinically unstable fronts were also explored, in particular the evolution of a mixed-layer front in the presence of forcing. In this case, an asymmetry appears because of the forcing. The mixed-layer model was coupled to the adiabatic model and additional application of the couple model is being explored.